FIG.1

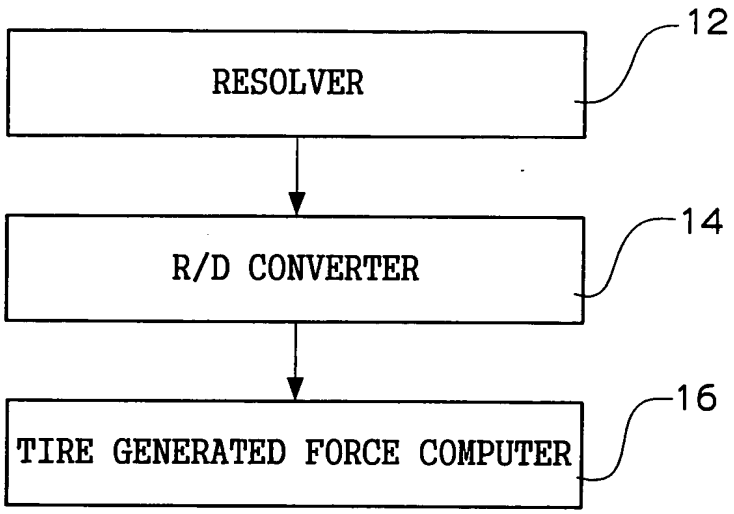

RESOLVER
12
R/D CONVERTER
14
TIRE GENERATED FORCE COMPUTER
16

FIG.2

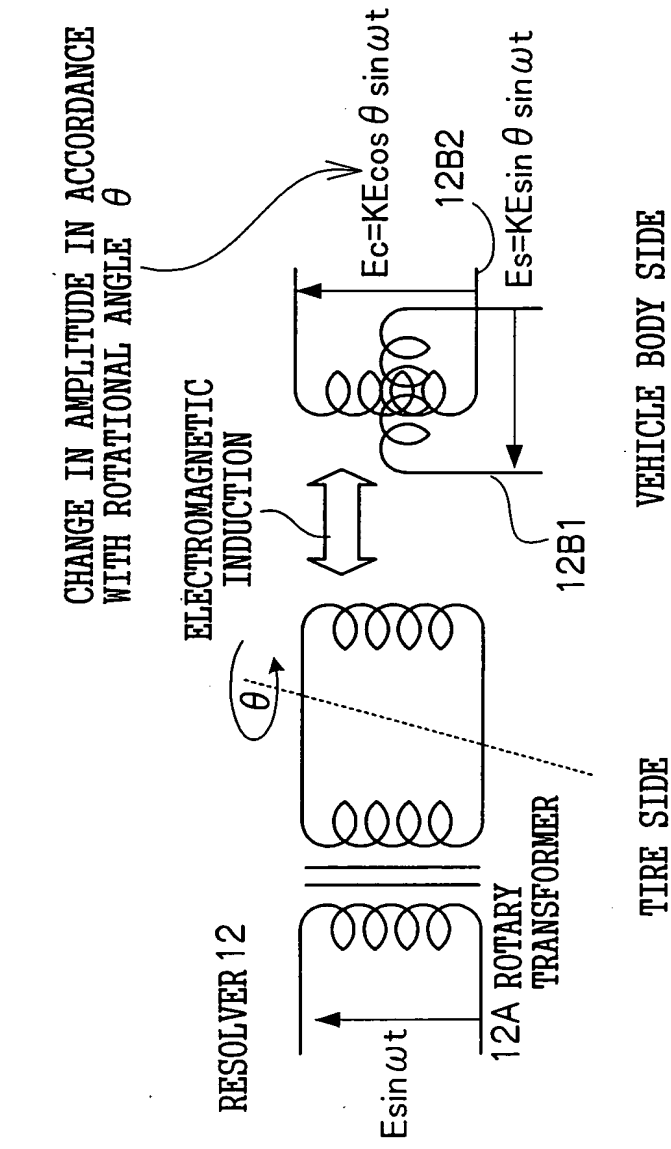

CHANGE IN AMPLITUDE IN ACCORDANCE WITH ROTATIONAL ANGLE θ
ELECTROMAGNETIC INDUCTION
Ec=KEcos θ sin ωt
Es=KEsin θ sin ωt
12B2
12B1
θ
RESOLVER 12
Esin ωt
12A ROTARY TRANSFORMER
TIRE SIDE
VEHICLE BODY SIDE

FIG.3

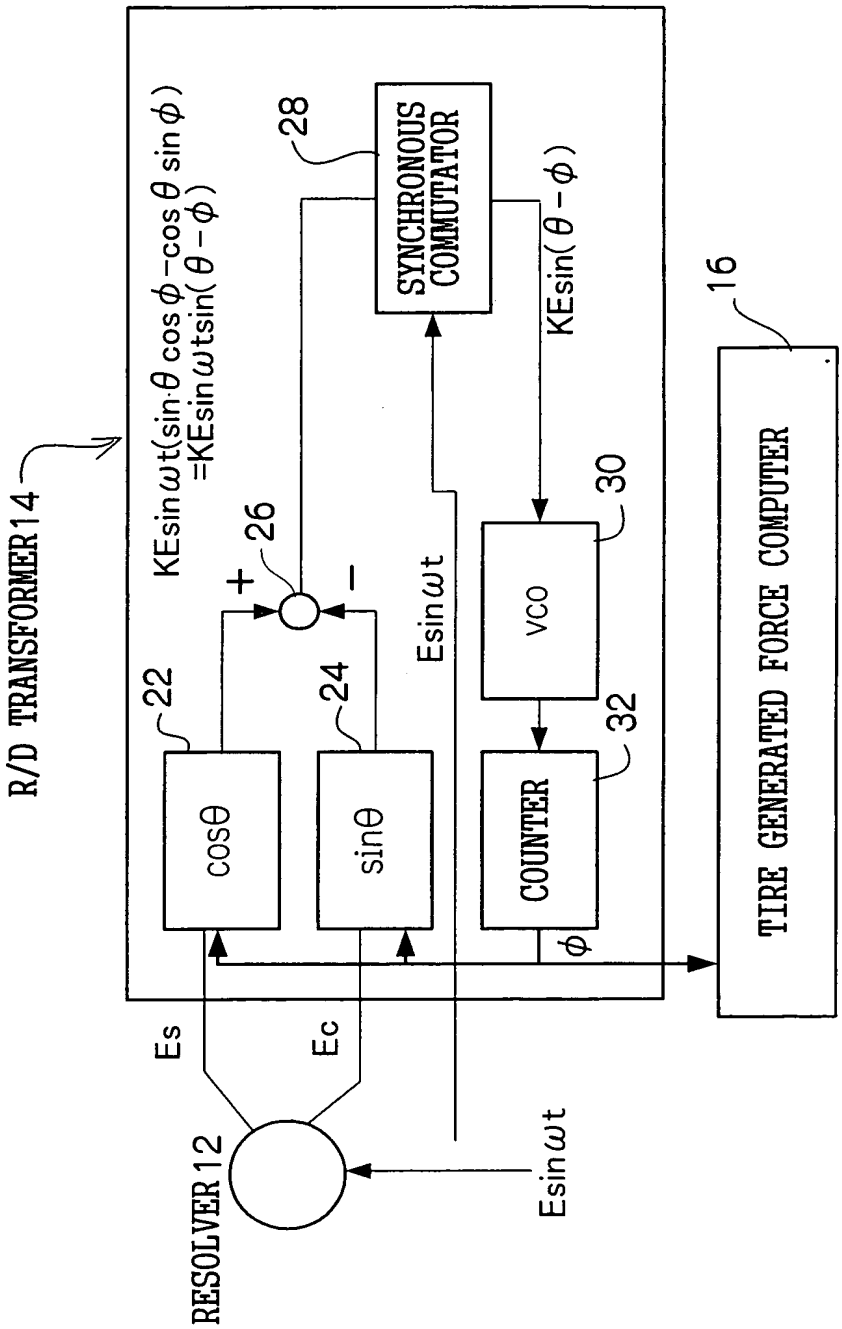

R/D TRANSFORMER 14
KEsinωt(sinθ cosφ−cosθ sinφ)
=KEsinωtsin(θ−φ)
28
SYNCHRONOUS COMMUTATOR
KEsin(θ−φ)
16
TIRE GENERATED FORCE COMPUTER
26
+
−
Esinωt
VCO
30
22
24
cosθ
sinθ
COUNTER
32
φ
Es
Ec
RESOLVER 12
Esinωt

FIG.4

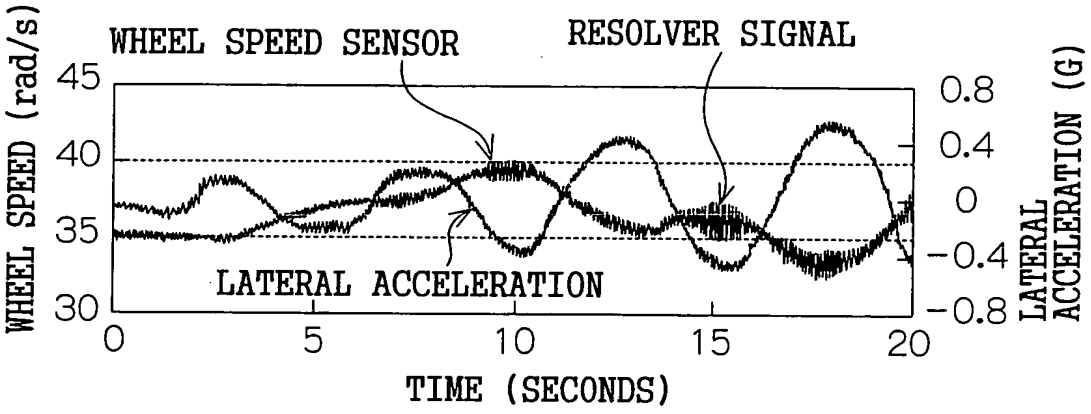

WHEEL SPEED SENSOR
RESOLVER SIGNAL
LATERAL ACCELERATION
WHEEL SPEED (rad/s)
45
40
35
30
0
5
10
15
20
TIME (SECONDS)
0.8
0.4
0
-0.4
-0.8
LATERAL ACCELERATION (G)

FIG.5

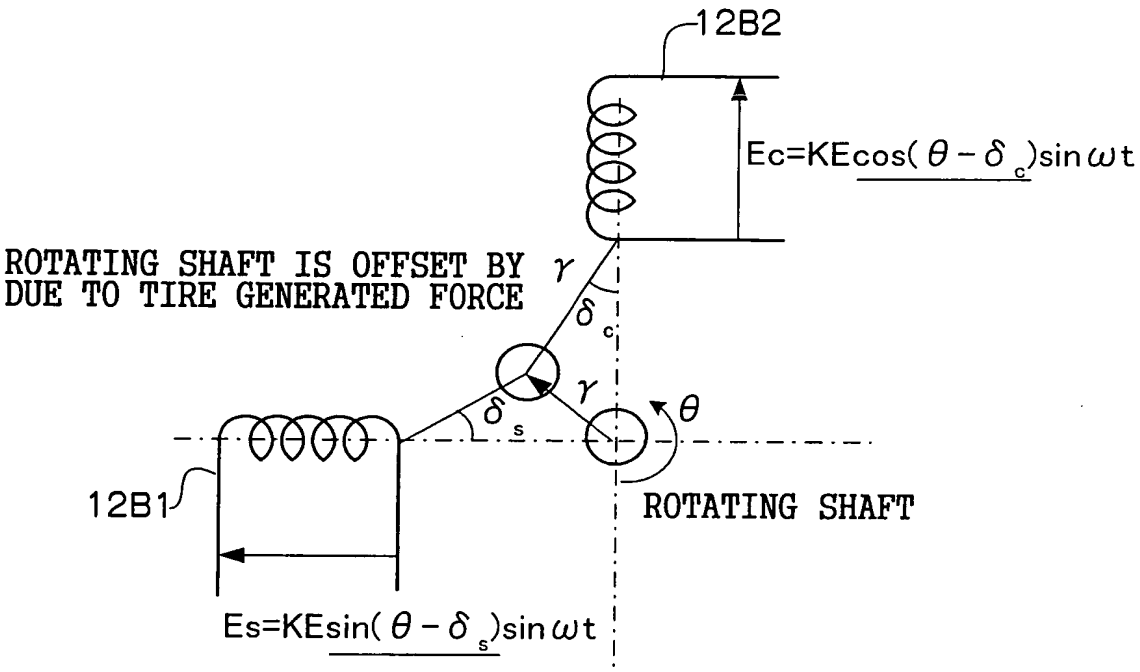

12B2
Ec=KEcos(θ − δ c)sin ωt
ROTATING SHAFT IS OFFSET BY
DUE TO TIRE GENERATED FORCE
γ
δ c
γ
δ s
θ
12B1
ROTATING SHAFT
Es=KEsin(θ − δ s)sin ωt

FIG.6

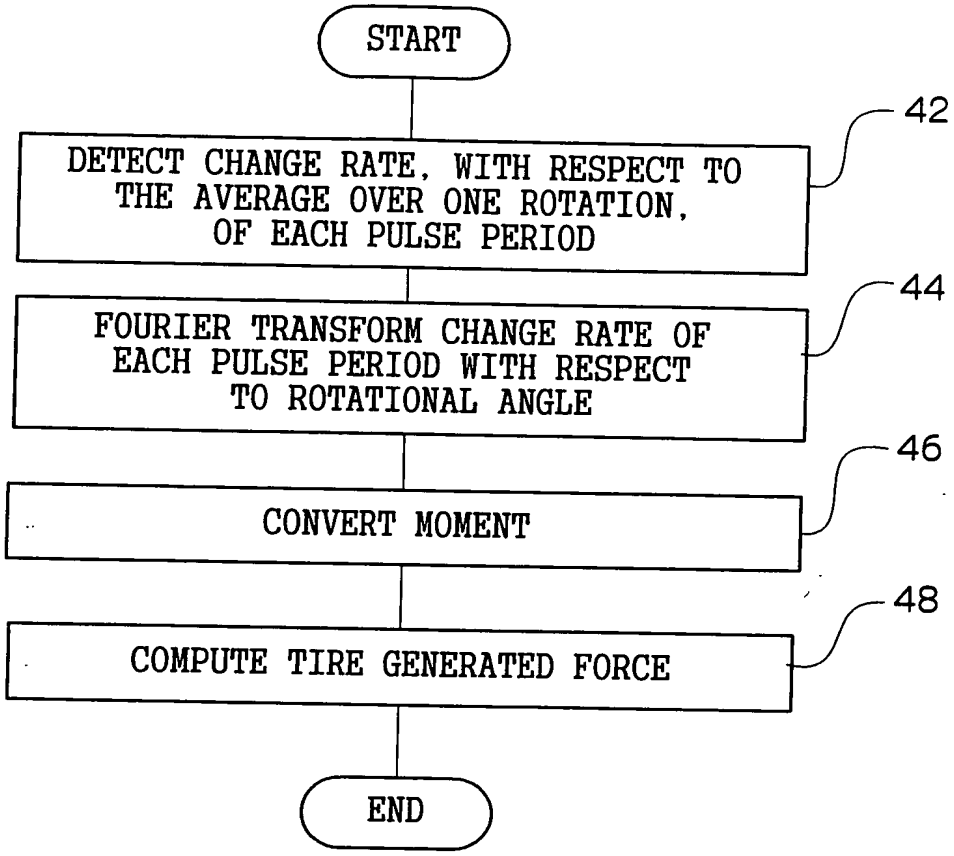

START
DETECT CHANGE RATE, WITH RESPECT TO THE AVERAGE OVER ONE ROTATION, OF EACH PULSE PERIOD
42
FOURIER TRANSFORM CHANGE RATE OF EACH PULSE PERIOD WITH RESPECT TO ROTATIONAL ANGLE
44
CONVERT MOMENT
46
COMPUTE TIRE GENERATED FORCE
48
END

FIG.7

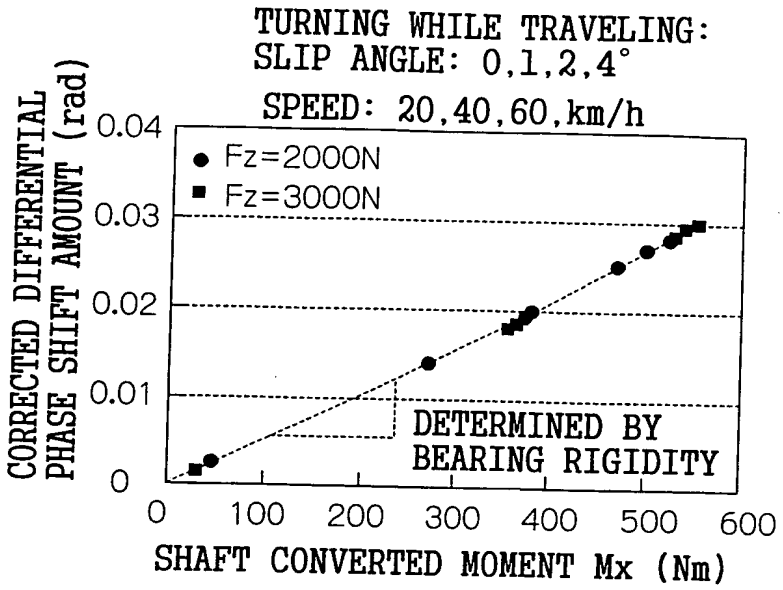

TURNING WHILE TRAVELING:
SLIP ANGLE: 0,1,2,4°
SPEED: 20,40,60,km/h
CORRECTED DIFFERENTIAL PHASE SHIFT AMOUNT (rad)
0.04
0.03
0.02
0.01
0
Fz=2000N
Fz=3000N
DETERMINED BY BEARING RIGIDITY
0
100
200
300
400
500
600
SHAFT CONVERTED MOMENT Mx (Nm)

FIG.8

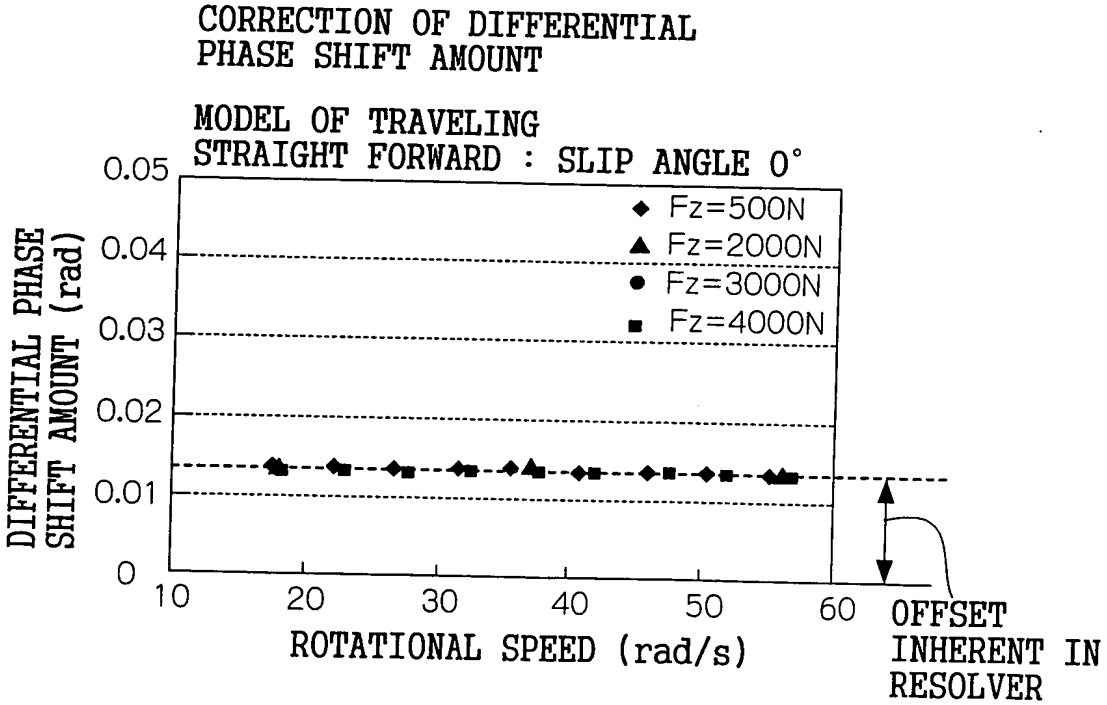

CORRECTION OF DIFFERENTIAL PHASE SHIFT AMOUNT
MODEL OF TRAVELING
STRAIGHT FORWARD : SLIP ANGLE 0°
DIFFERENTIAL PHASE SHIFT AMOUNT (rad)
0.05
0.04
0.03
0.02
0.01
0
Fz=500N
Fz=2000N
Fz=3000N
Fz=4000N
10
20
30
40
50
60
ROTATIONAL SPEED (rad/s)
OFFSET INHERENT IN RESOLVER

FIG.9A

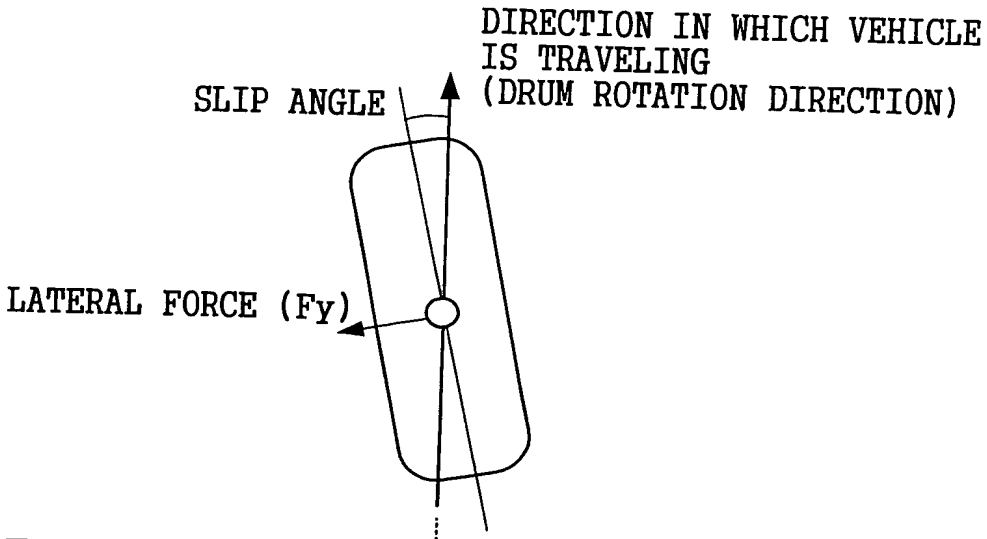

DIRECTION IN WHICH VEHICLE
IS TRAVELING
(DRUM ROTATION DIRECTION)
SLIP ANGLE
LATERAL FORCE (Fy)

FIG.9B

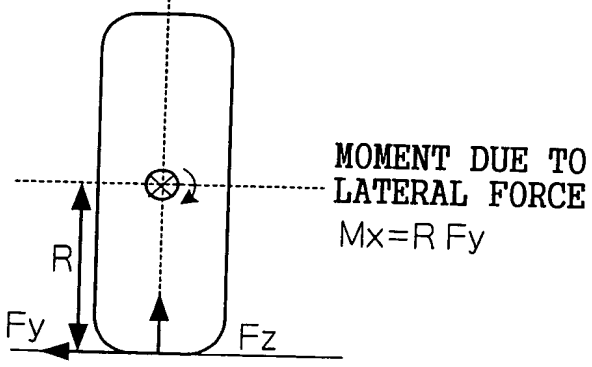

MOMENT DUE TO
LATERAL FORCE
Mx=R Fy
R
Fy
Fz

FIG.10A

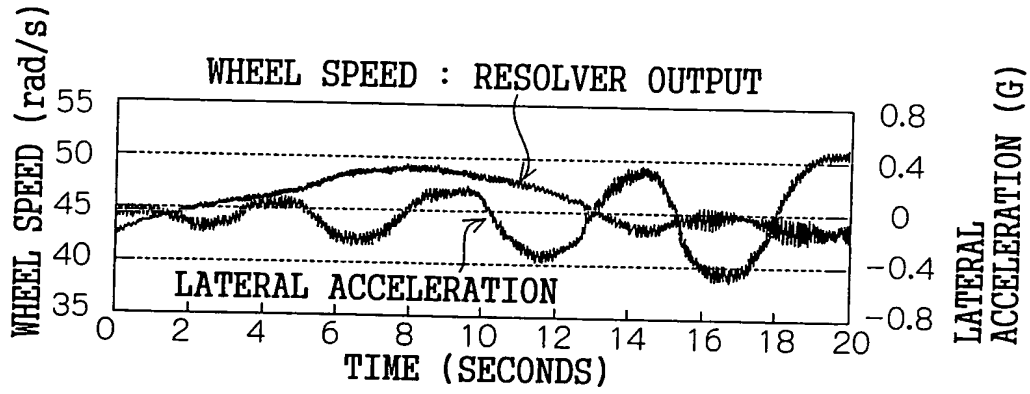
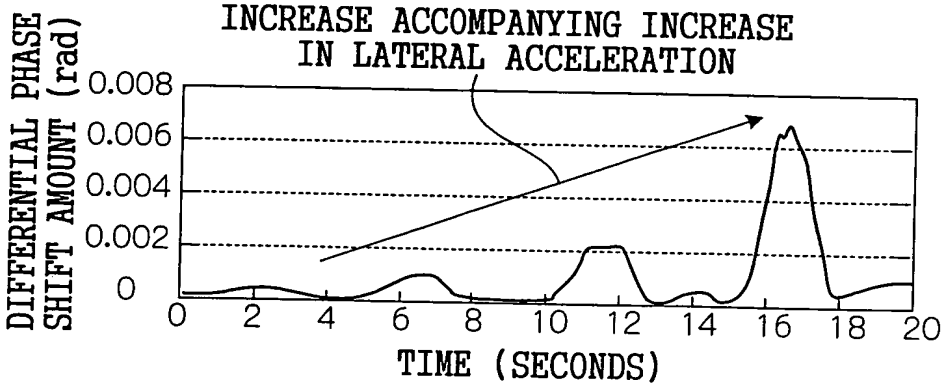


FIG.10B



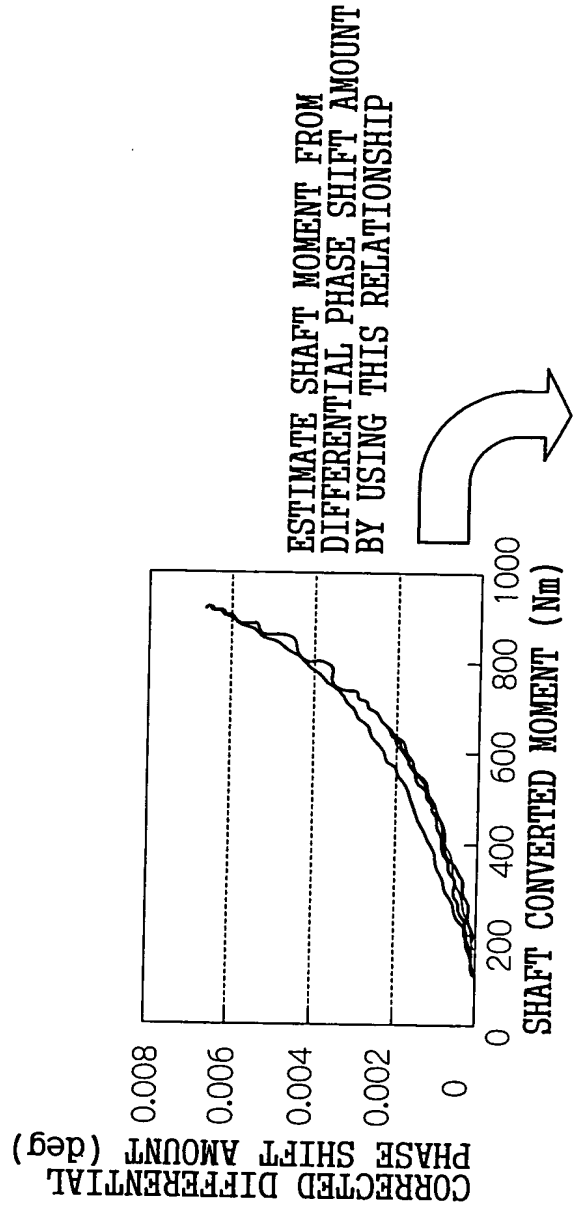


FIG.11A

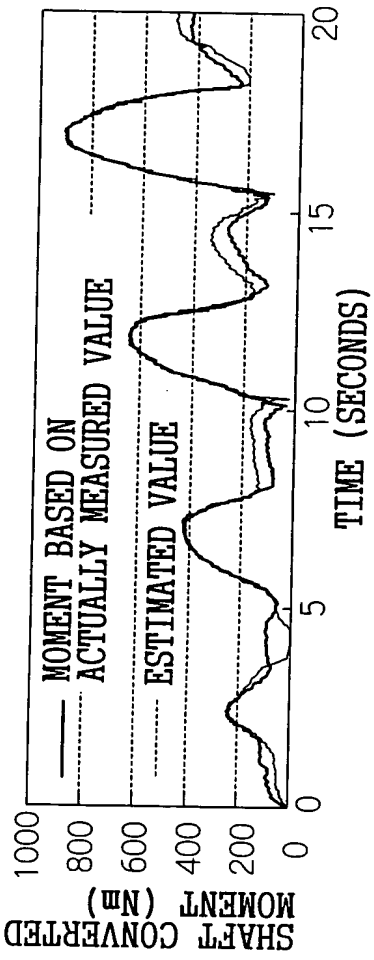


FIG.11B

FIG.12

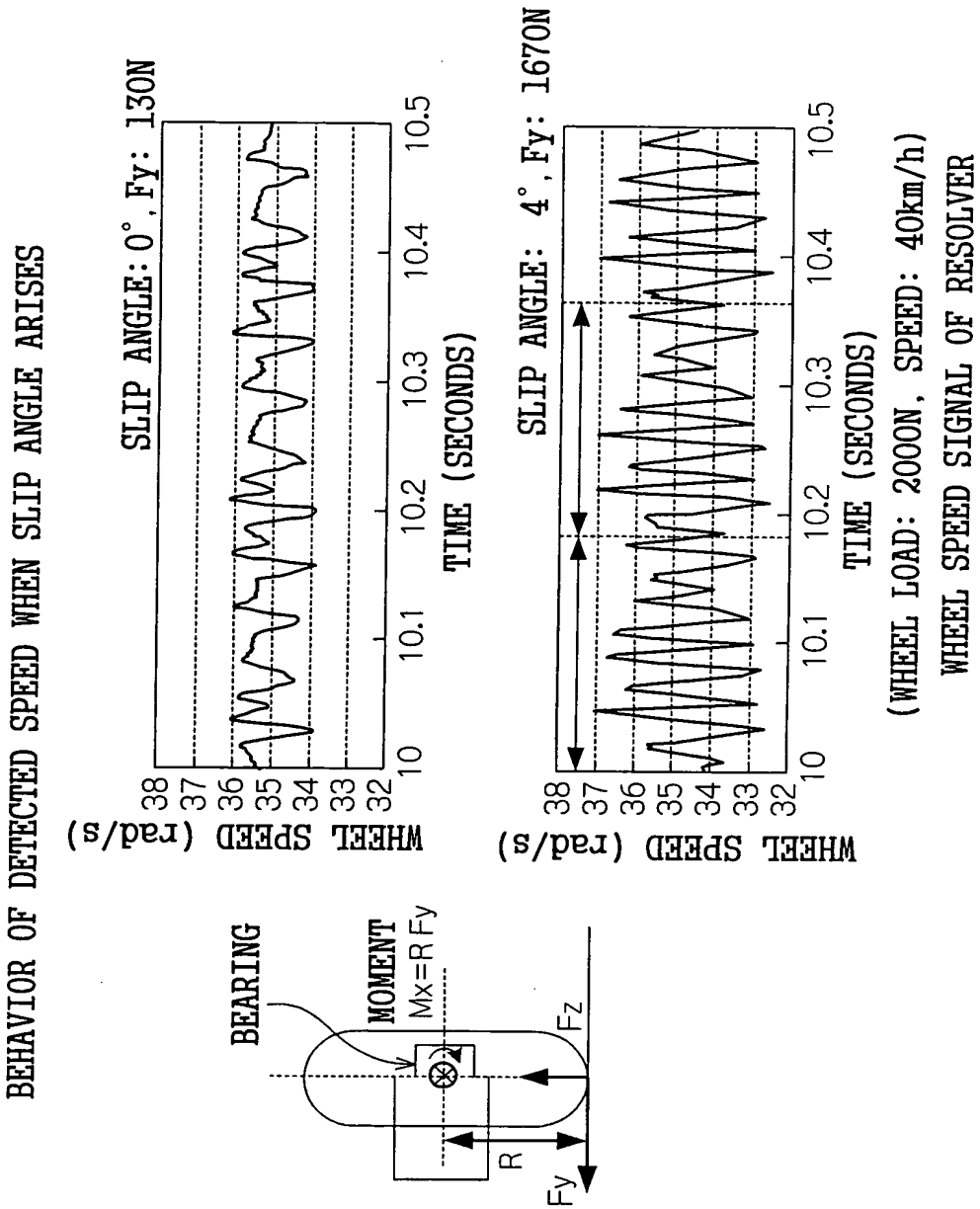

BEHAVIOR OF DETECTED SPEED WHEN SLIP ANGLE ARISES
SLIP ANGLE: 0°, Fy: 130N
WHEEL SPEED (rad/s)
38
37
36
35
34
33
32
10
10.1
10.2
10.3
10.4
10.5
TIME (SECONDS)
SLIP ANGLE: 4°, Fy: 1670N
WHEEL SPEED (rad/s)
TIME (SECONDS)
(WHEEL LOAD: 2000N, SPEED: 40km/h)
WHEEL SPEED SIGNAL OF RESOLVER
BEARING
MOMENT
Mx=R Fy
Fz
R
Fy

FIG.13

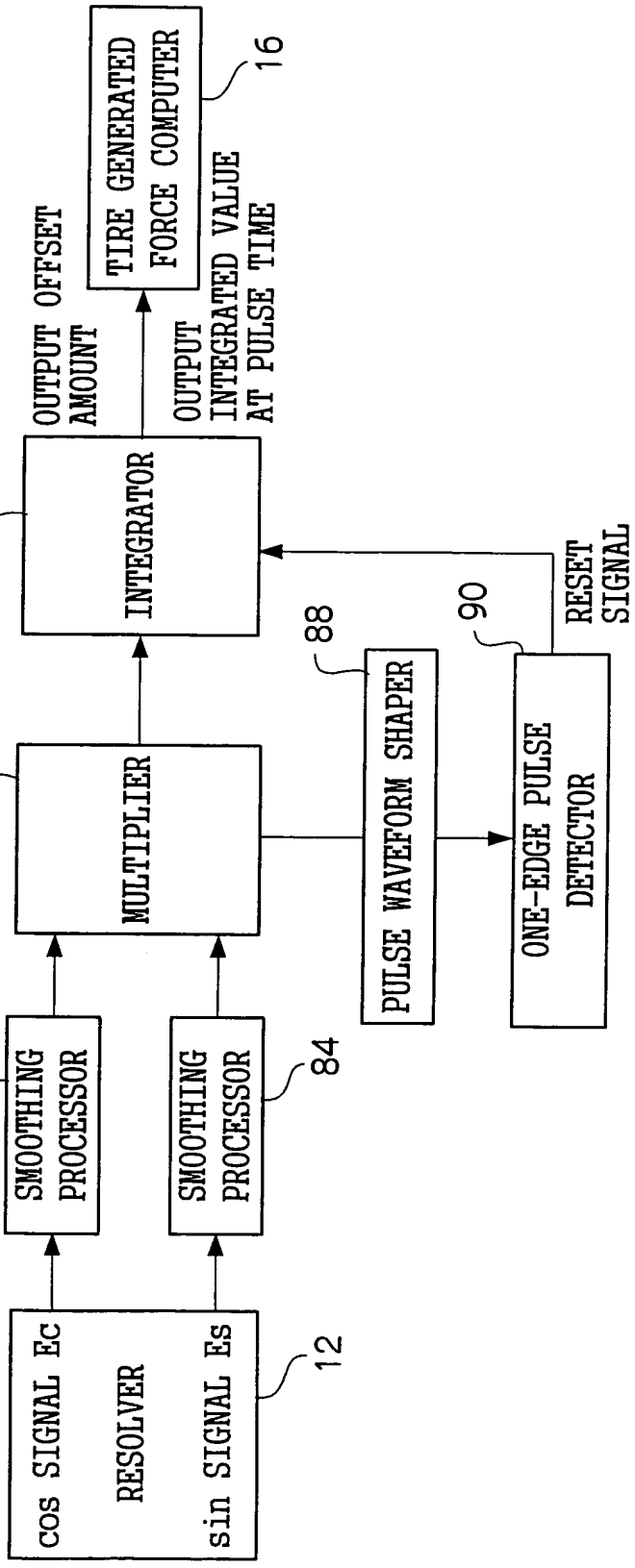

TIRE GENERATED FORCE COMPUTER
16
OUTPUT OFFSET AMOUNT
OUTPUT INTEGRATED VALUE AT PULSE TIME
92
INTEGRATOR
RESET SIGNAL
88
90
86
MULTIPLIER
PULSE WAVEFORM SHAPER
ONE-EDGE PULSE DETECTOR
82
SMOOTHING PROCESSOR
SMOOTHING PROCESSOR
84
cos SIGNAL Ec
RESOLVER
sin SIGNAL Es
12

FIG.14

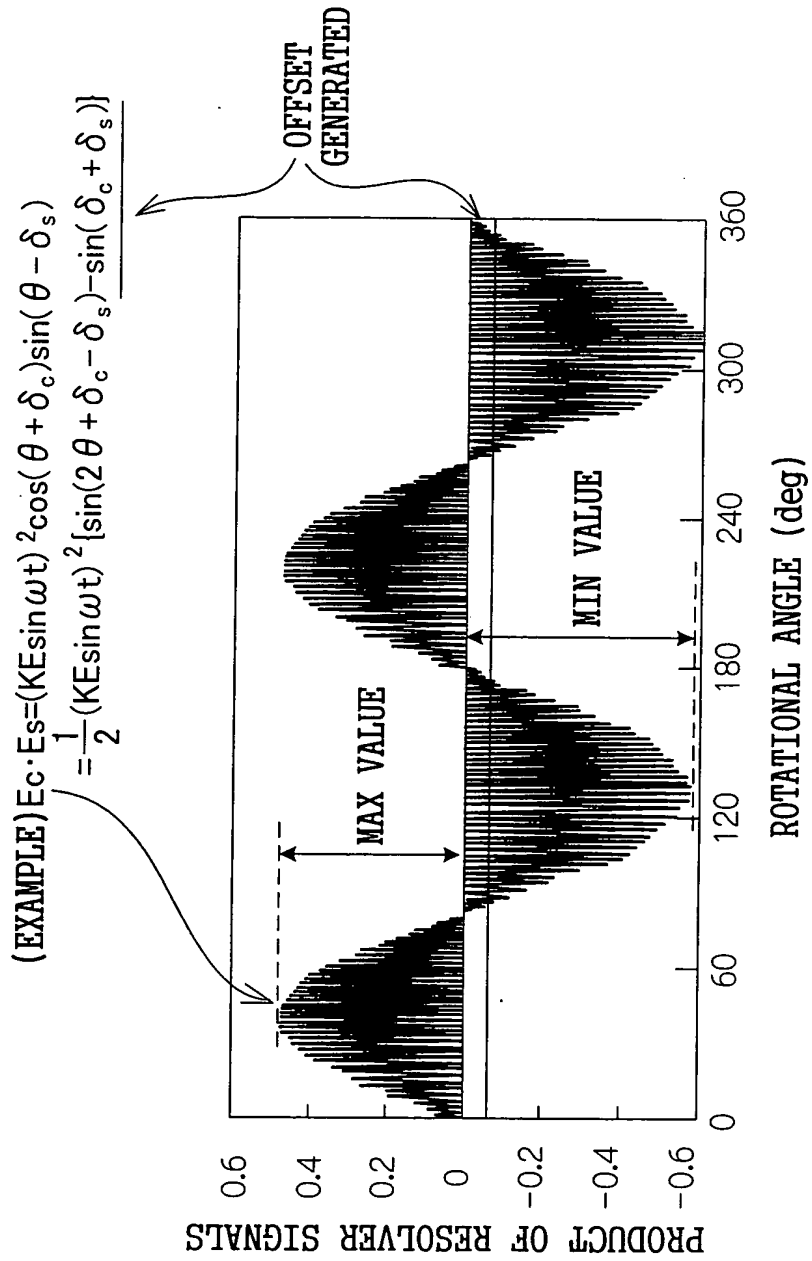


FIG.15

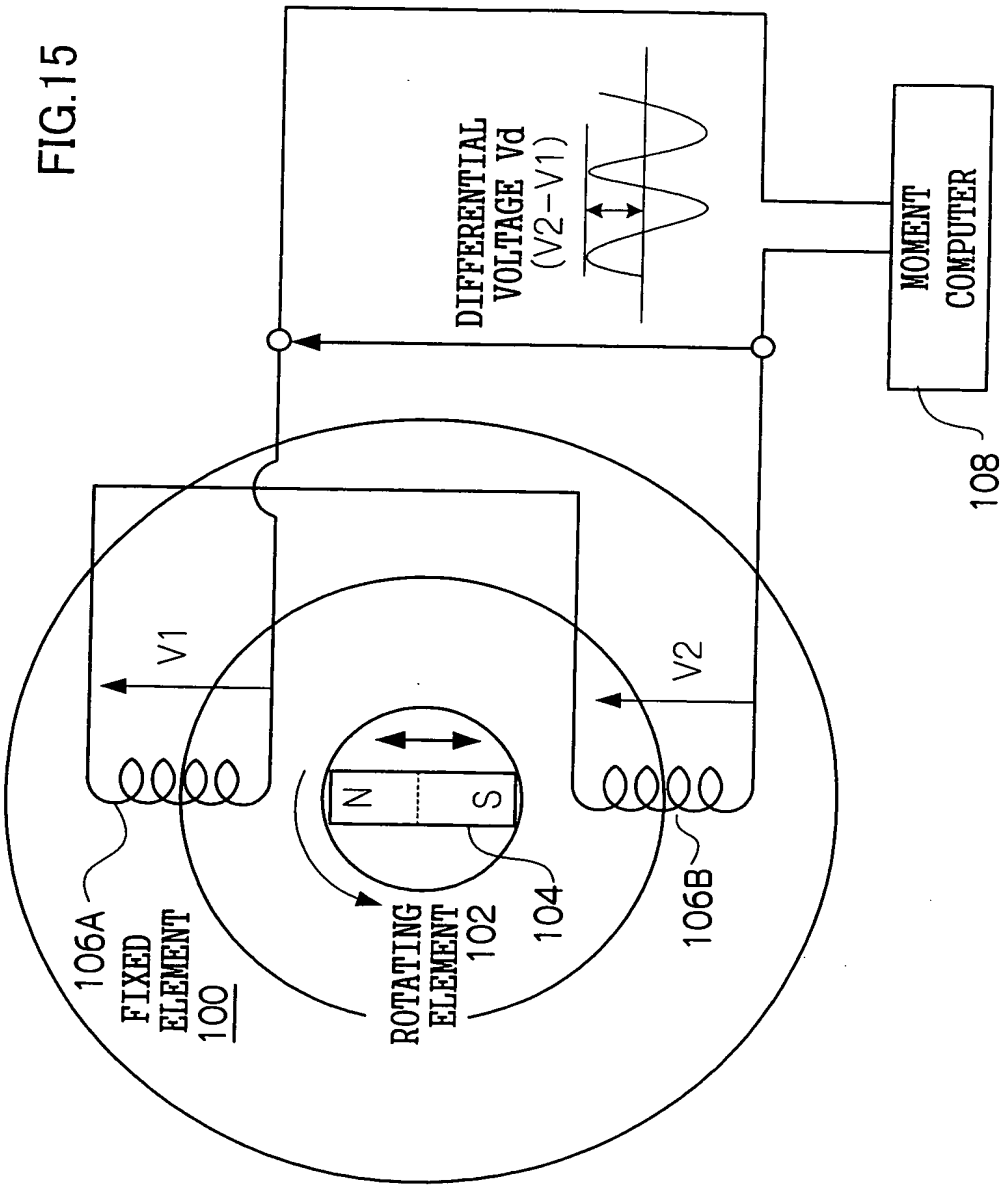

DIFFERENTIAL VOLTAGE Vd (V2−V1)
MOMENT COMPUTER
108
V1
V2
N
S
106A
FIXED ELEMENT 100
ROTATING ELEMENT 102
104
106B

FIG.16A

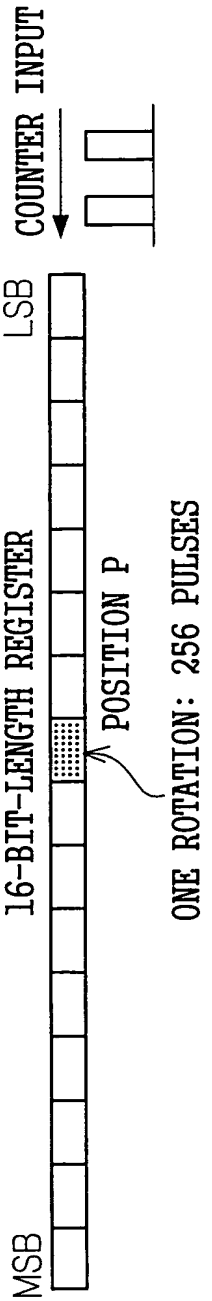


FIG.16B

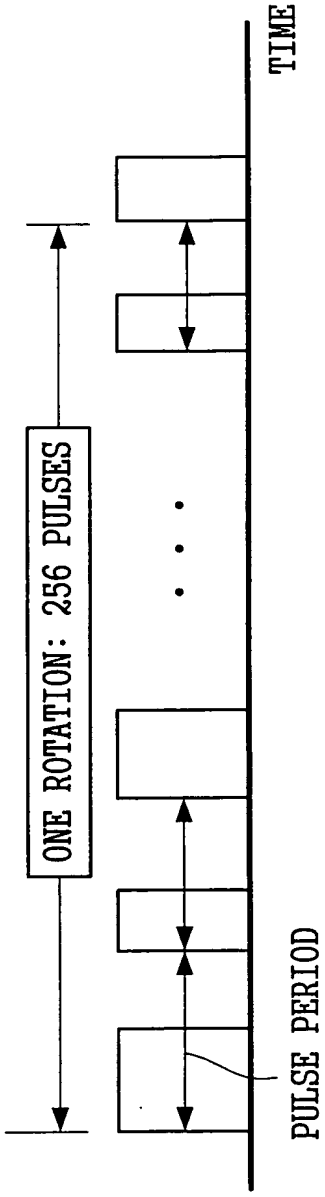


FIG.17

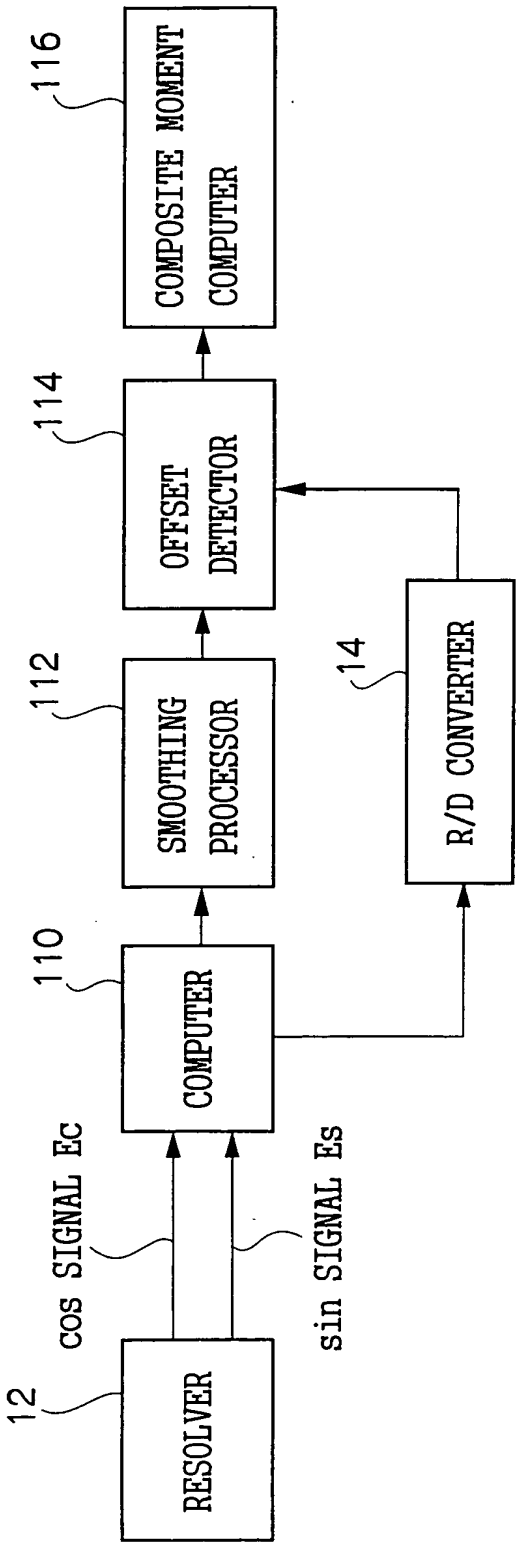

12
RESOLVER
cos SIGNAL Ec
sin SIGNAL Es
110
COMPUTER
112
SMOOTHING PROCESSOR
114
OFFSET DETECTOR
116
COMPOSITE MOMENT COMPUTER
14
R/D CONVERTER

FIG.18A

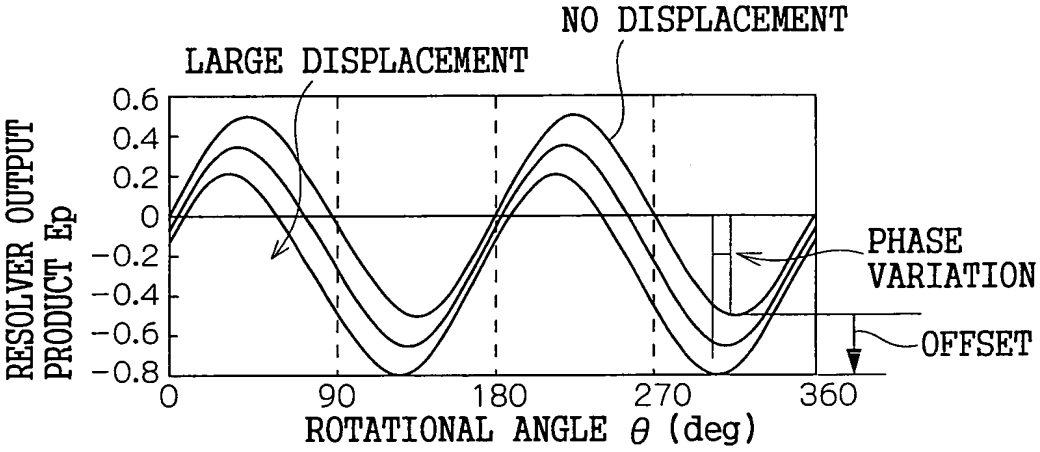


FIG.18B

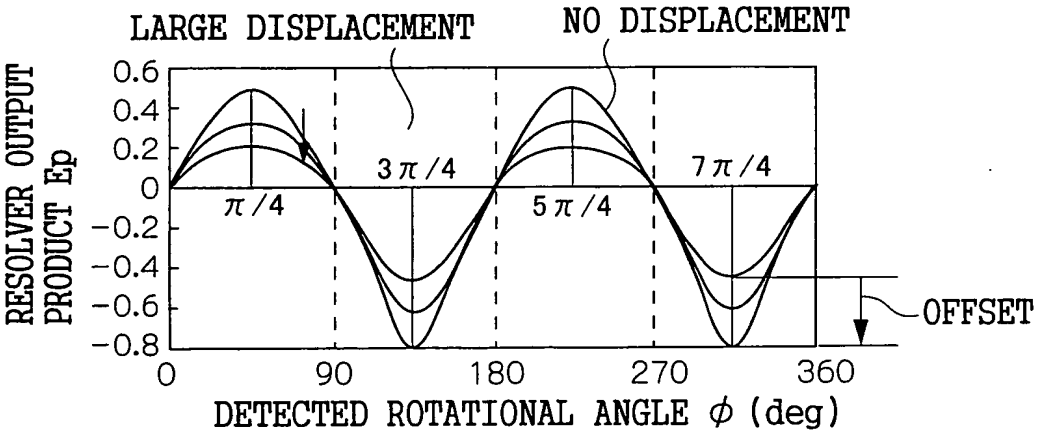


FIG.19

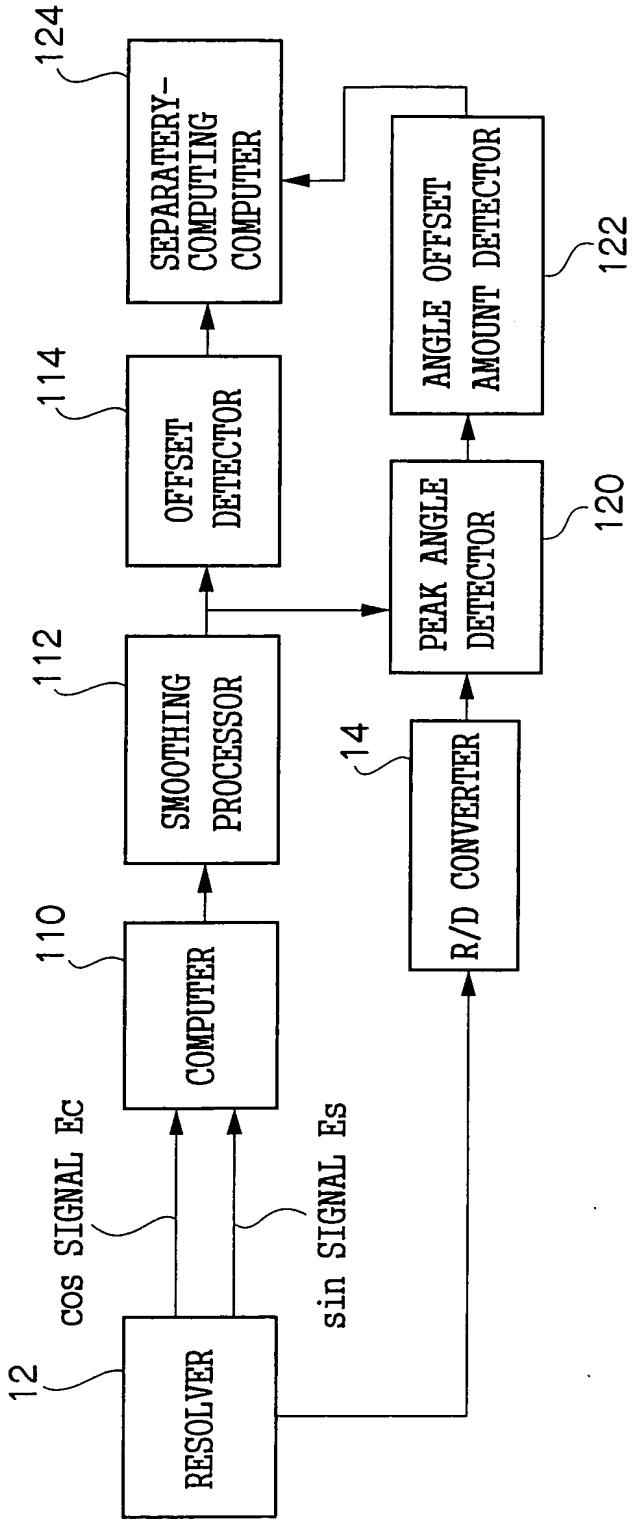
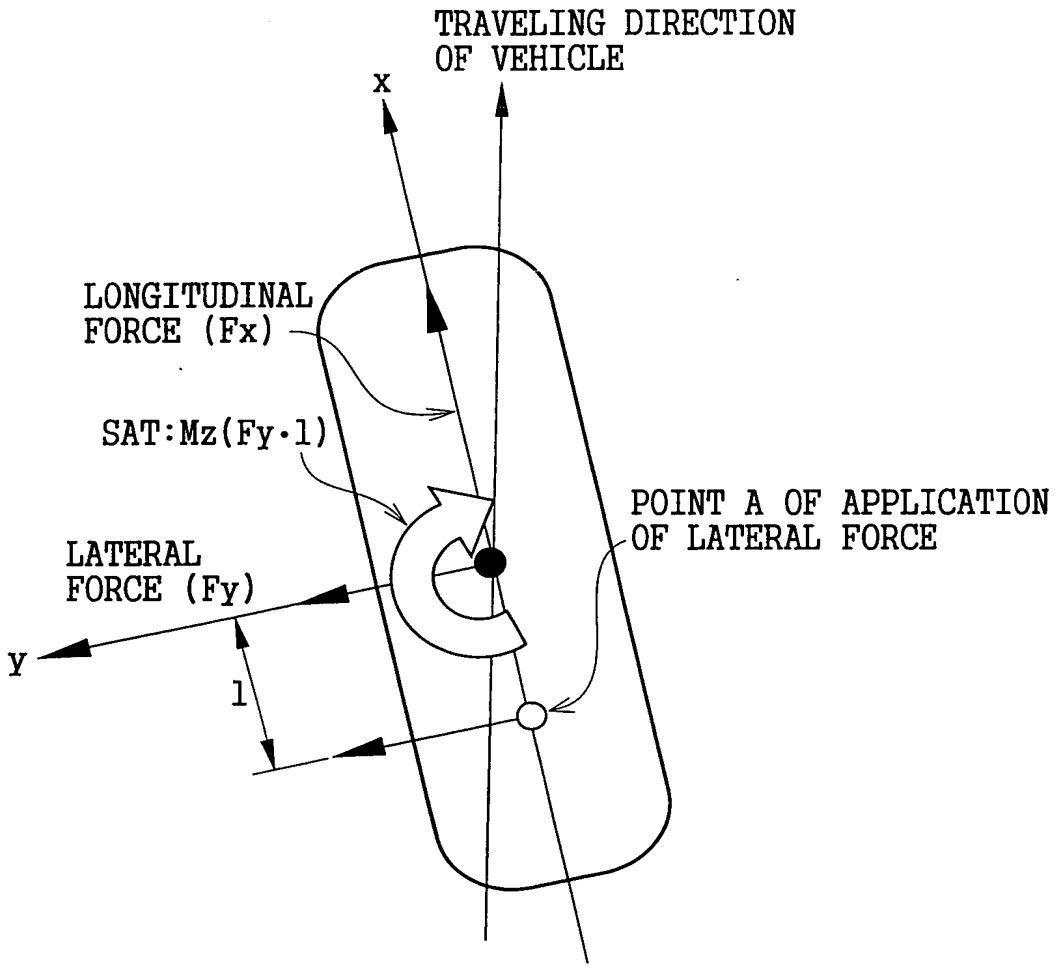

12
RESOLVER
cos SIGNAL Ec
sin SIGNAL Es
110
COMPUTER
112
SMOOTHING PROCESSOR
114
OFFSET DETECTOR
124
SEPARATERY-COMPUTING COMPUTER
14
R/D CONVERTER
120
PEAK ANGLE DETECTOR
122
ANGLE OFFSET AMOUNT DETECTOR

FIG.20


TRAVELING DIRECTION
OF VEHICLE
x
LONGITUDINAL
FORCE (Fx)
SAT:Mz(Fy·l)
POINT A OF APPLICATION
OF LATERAL FORCE
LATERAL
FORCE (Fy)
y
l

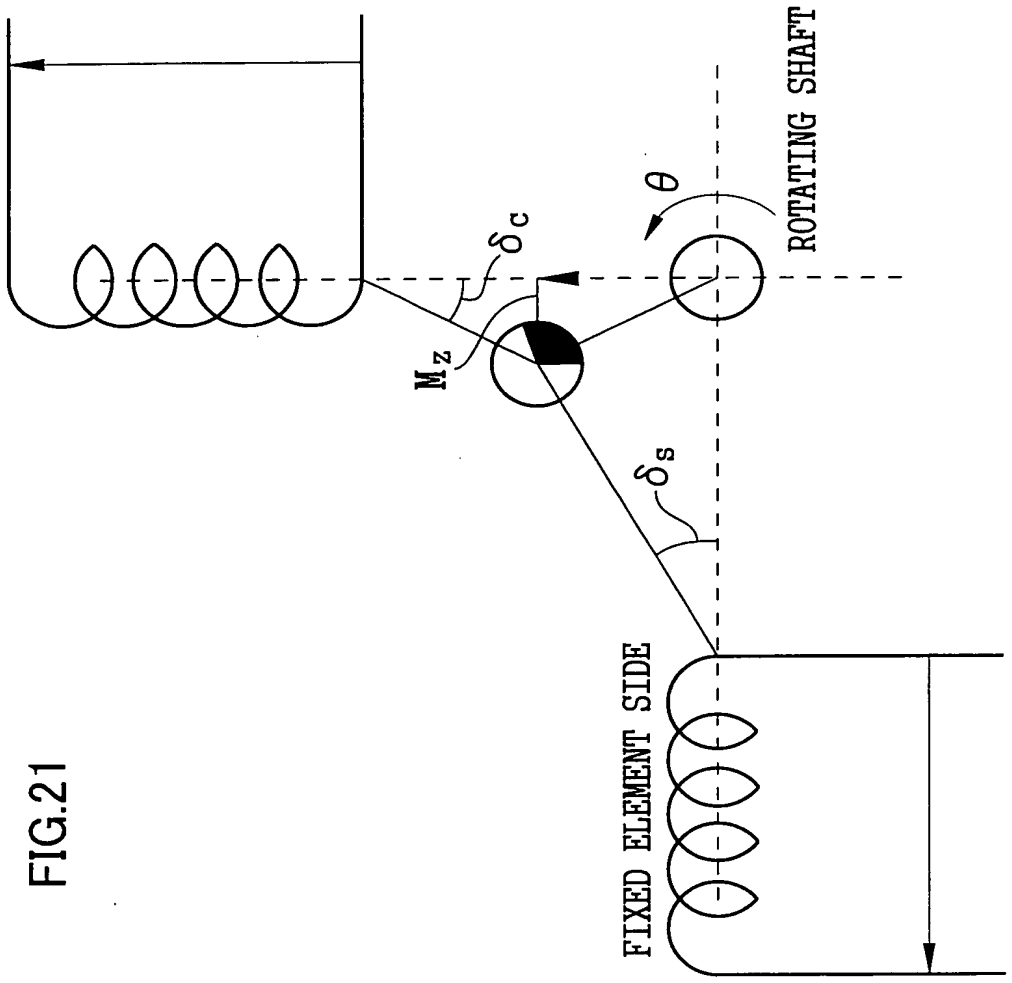


FIG.21

FIG.22

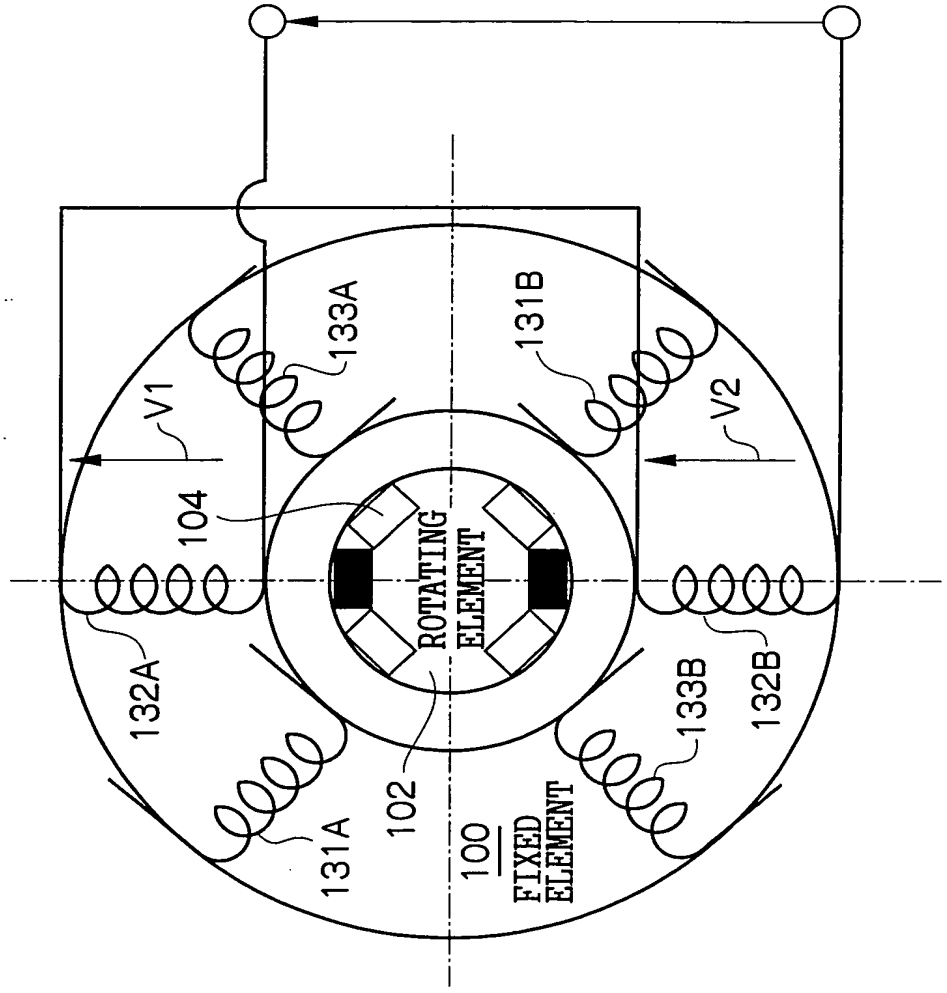

V1
V2
133A
131B
104
ROTATING ELEMENT
132A
132B
133B
131A
102
100
FIXED ELEMENT

FIG.23

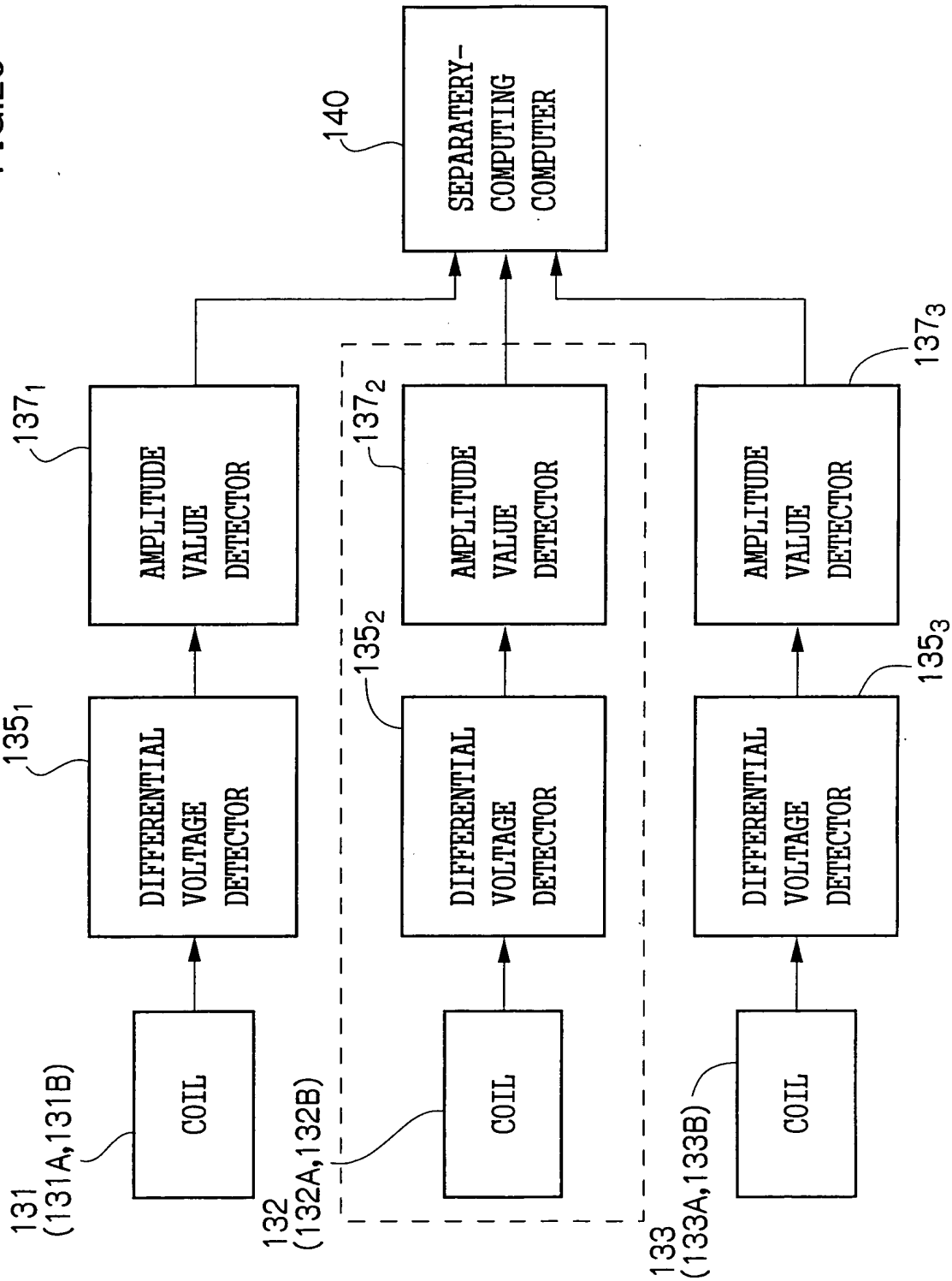

140
SEPARATERY-COMPUTING COMPUTER
137_1
137_2
137_3
AMPLITUDE VALUE DETECTOR
AMPLITUDE VALUE DETECTOR
AMPLITUDE VALUE DETECTOR
135_1
135_2
135_3
DIFFERENTIAL VOLTAGE DETECTOR
DIFFERENTIAL VOLTAGE DETECTOR
DIFFERENTIAL VOLTAGE DETECTOR
COIL
COIL
COIL
131 (131A,131B)
132 (132A,132B)
133 (133A,133B)

FIG.24A

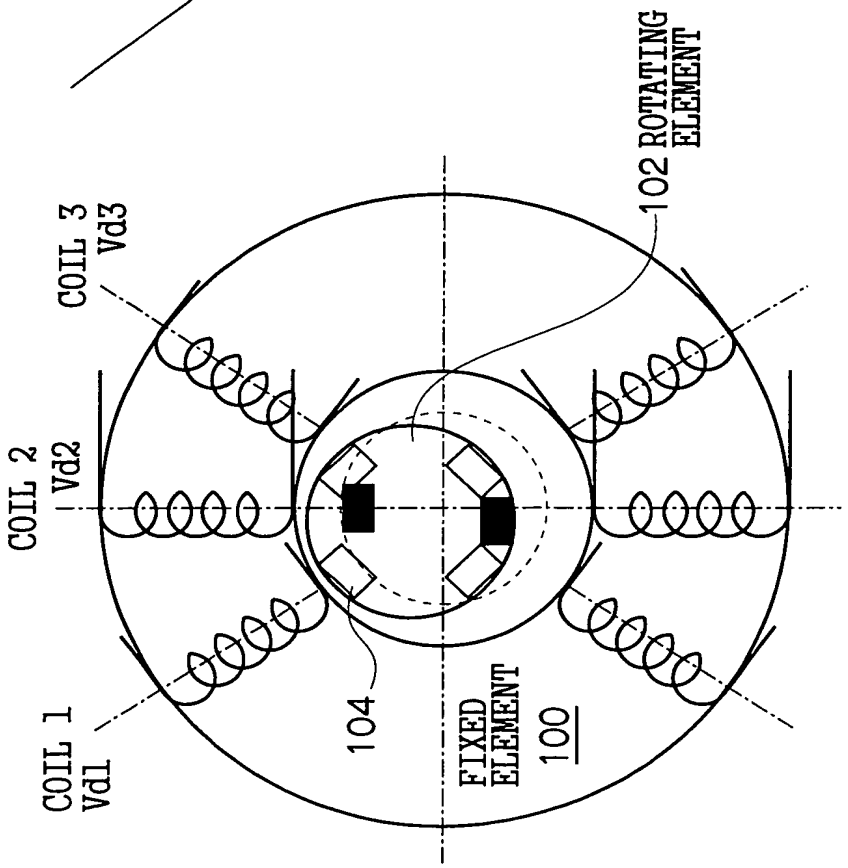


FIG.24B

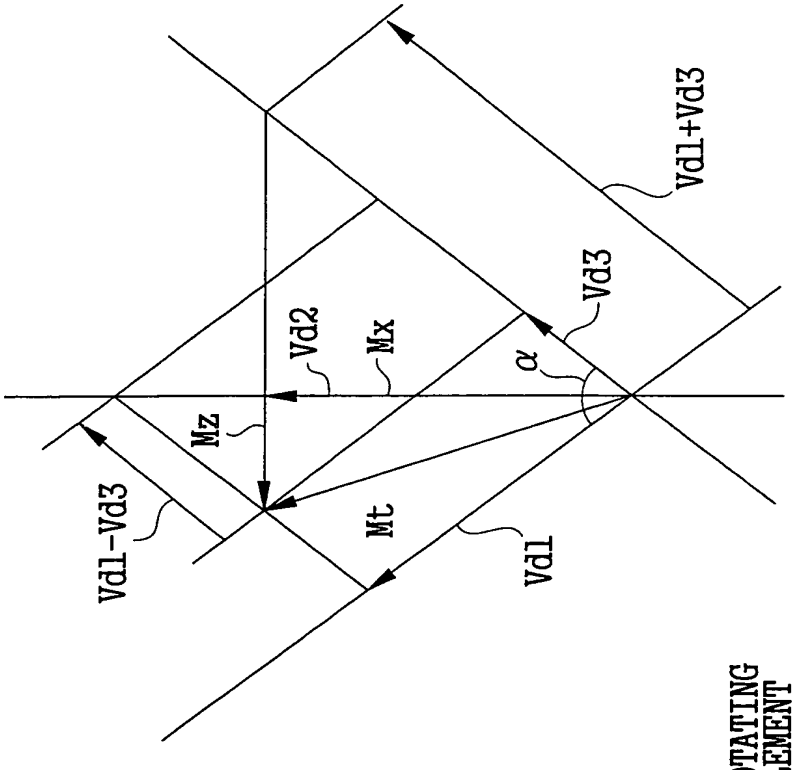


FIG.25

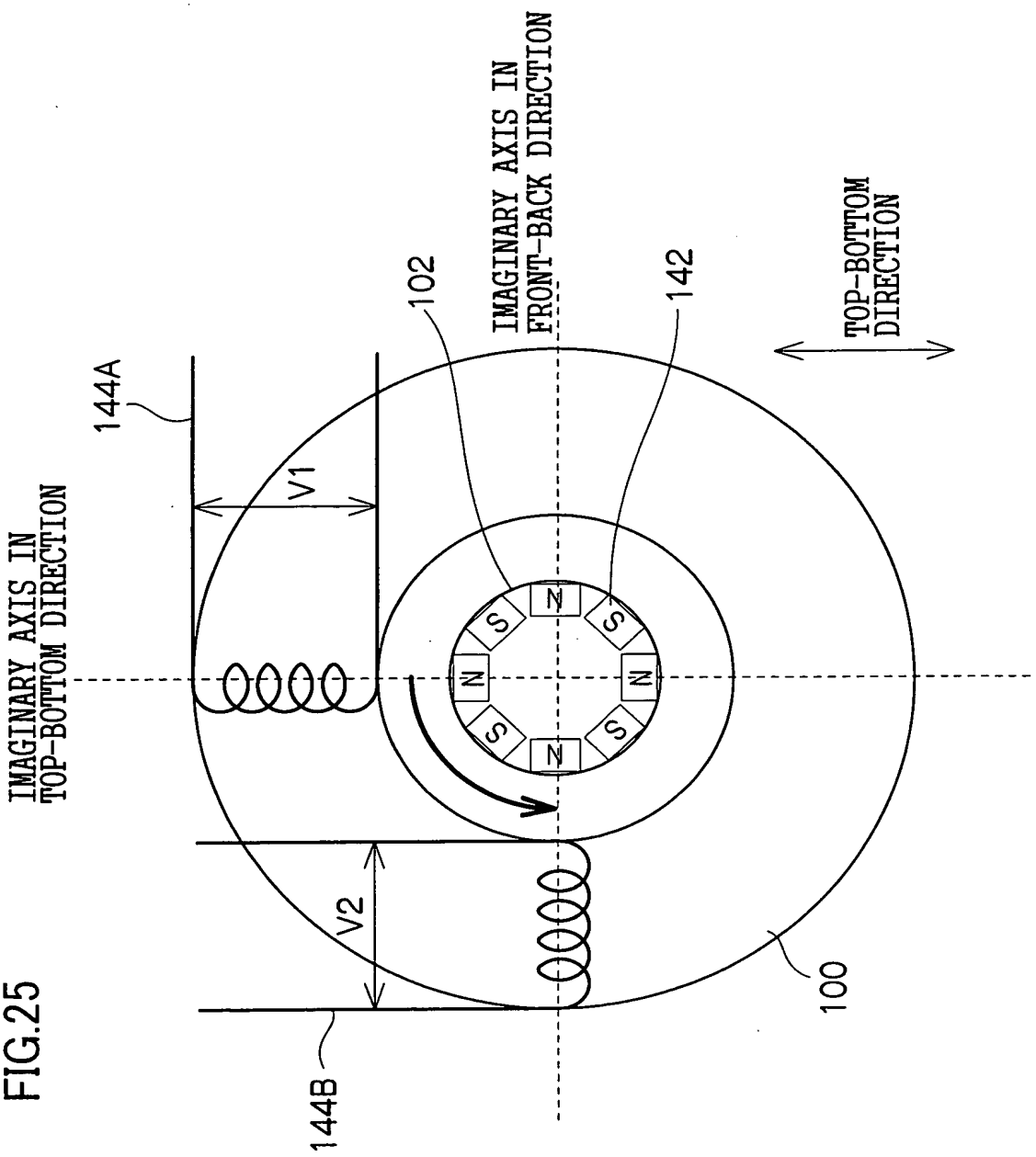

IMAGINARY AXIS IN
TOP-BOTTOM DIRECTION
IMAGINARY AXIS IN
FRONT-BACK DIRECTION
TOP-BOTTOM
DIRECTION
144A
144B
102
142
100
V1
V2
N
S

FIG.26

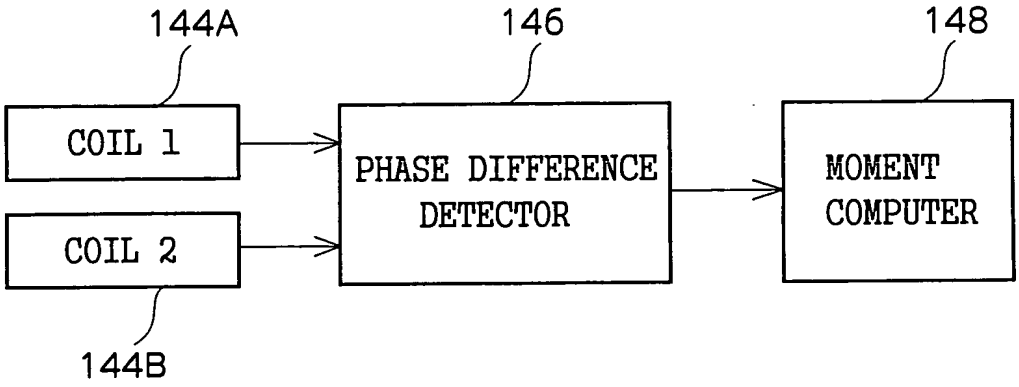

144A
146
148
COIL 1
COIL 2
PHASE DIFFERENCE DETECTOR
MOMENT COMPUTER
144B

FIG.27A

WHEN ROTATING SHAFT IS AT CENTER
→ PHASE DIFFERENCE BETWEEN V1 AND V2 IS ZERO

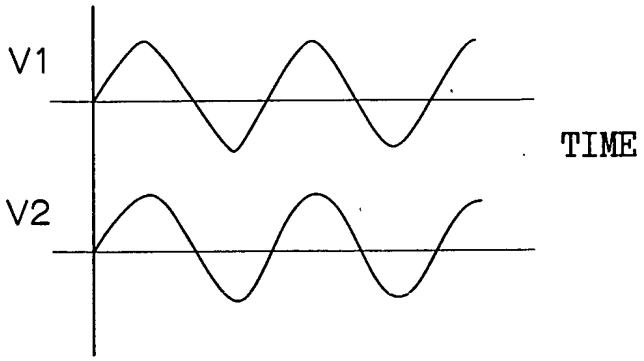
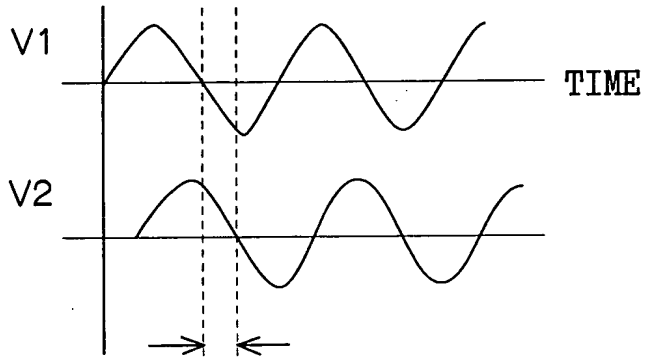


FIG.27B

WHEN ROTATING SHAFT IS DISPLACED
IN THE TOP-BOTTOM DIRECTION
→ A PHASE DIFFERENCE BETWEEN V1 AND V2 ARISES



WHEN ROTATING SHAFT IS DISPLACED UPWARD:
THE PHASE OF V2 LAGS

FIG.28

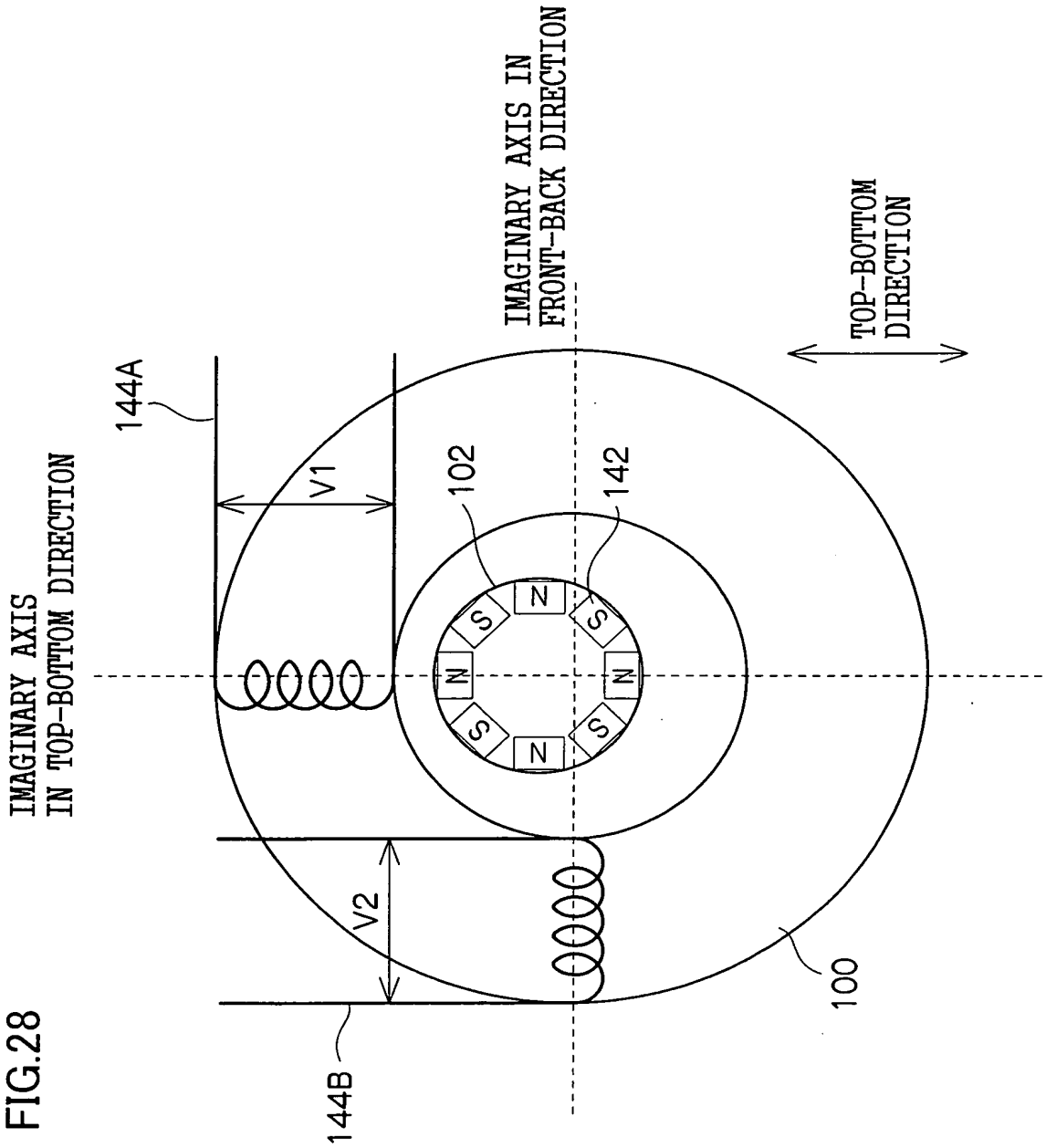

IMAGINARY AXIS
IN TOP-BOTTOM DIRECTION
IMAGINARY AXIS IN
FRONT-BACK DIRECTION
TOP-BOTTOM
DIRECTION
144A
144B
V1
V2
102
142
100
N
S

FIG.29

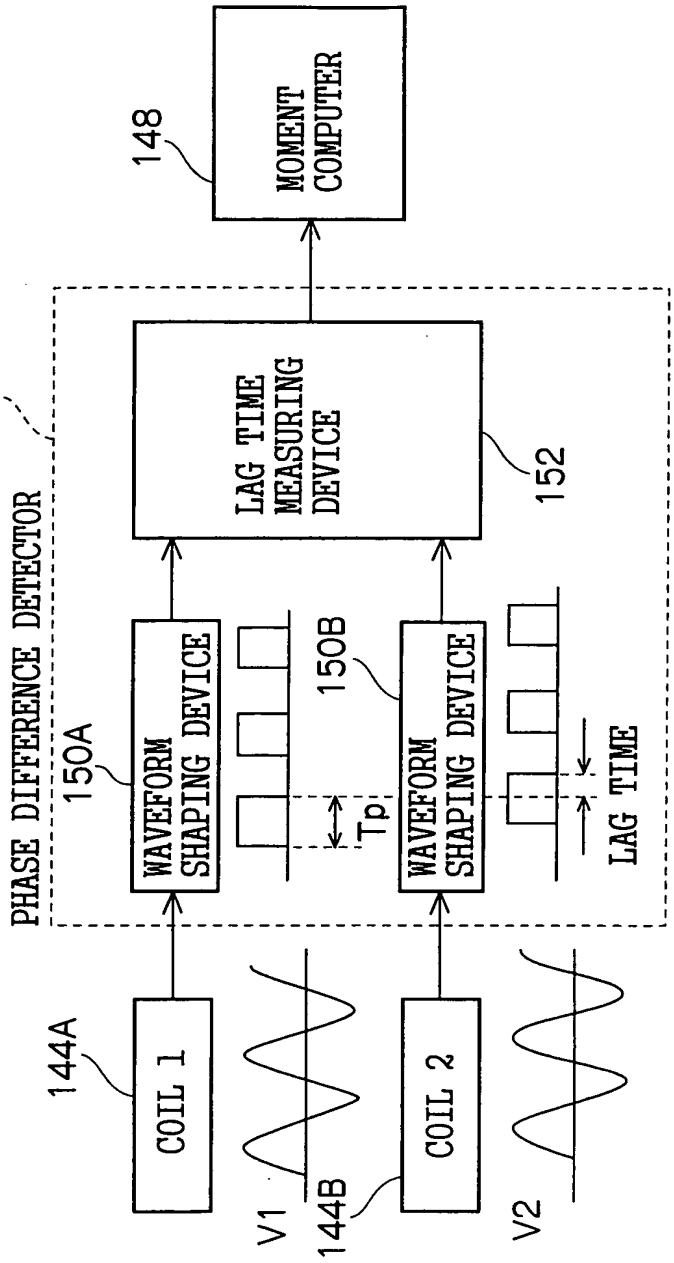

148
MOMENT COMPUTER
146
PHASE DIFFERENCE DETECTOR
LAG TIME MEASURING DEVICE
152
150A
WAVEFORM SHAPING DEVICE
150B
WAVEFORM SHAPING DEVICE
Tp
LAG TIME
144A
COIL 1
V1
144B
COIL 2
V2

FIG.30

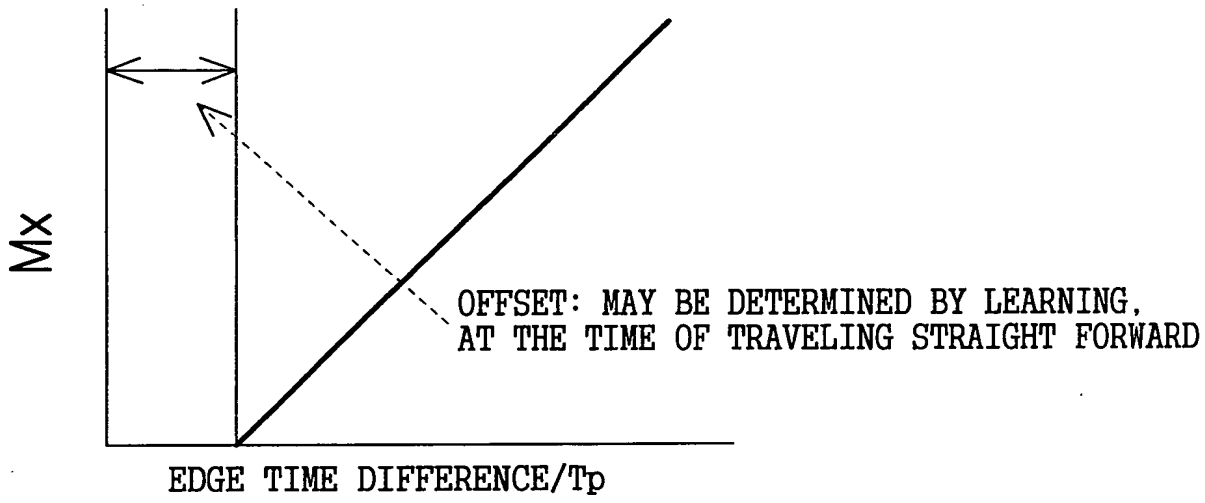

Mx
OFFSET: MAY BE DETERMINED BY LEARNING,
AT THE TIME OF TRAVELING STRAIGHT FORWARD
EDGE TIME DIFFERENCE/Tp

FIG.31

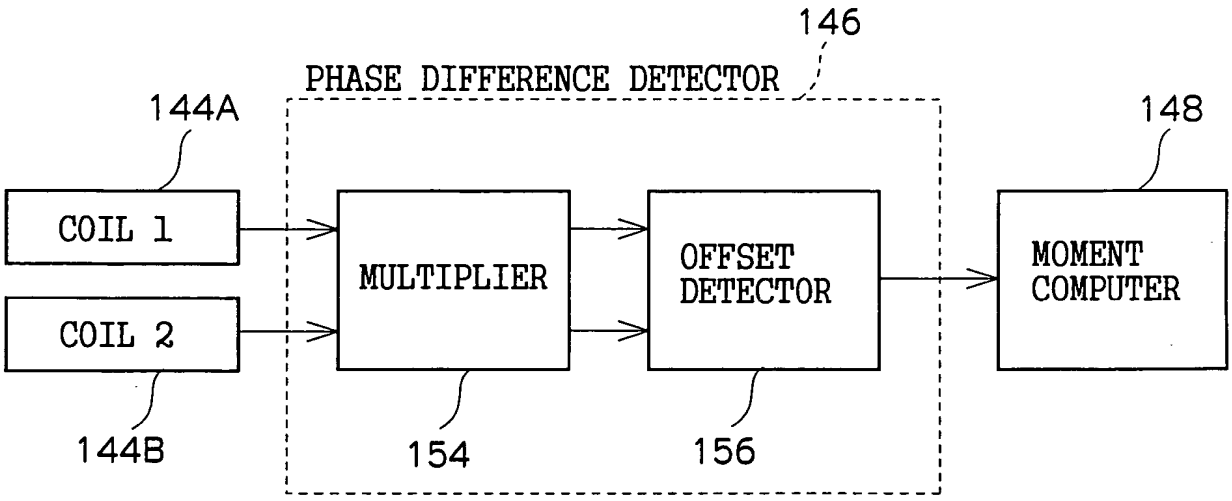

146
PHASE DIFFERENCE DETECTOR
144A
148
COIL 1
COIL 2
MULTIPLIER
OFFSET DETECTOR
MOMENT COMPUTER
144B
154
156

FIG.32

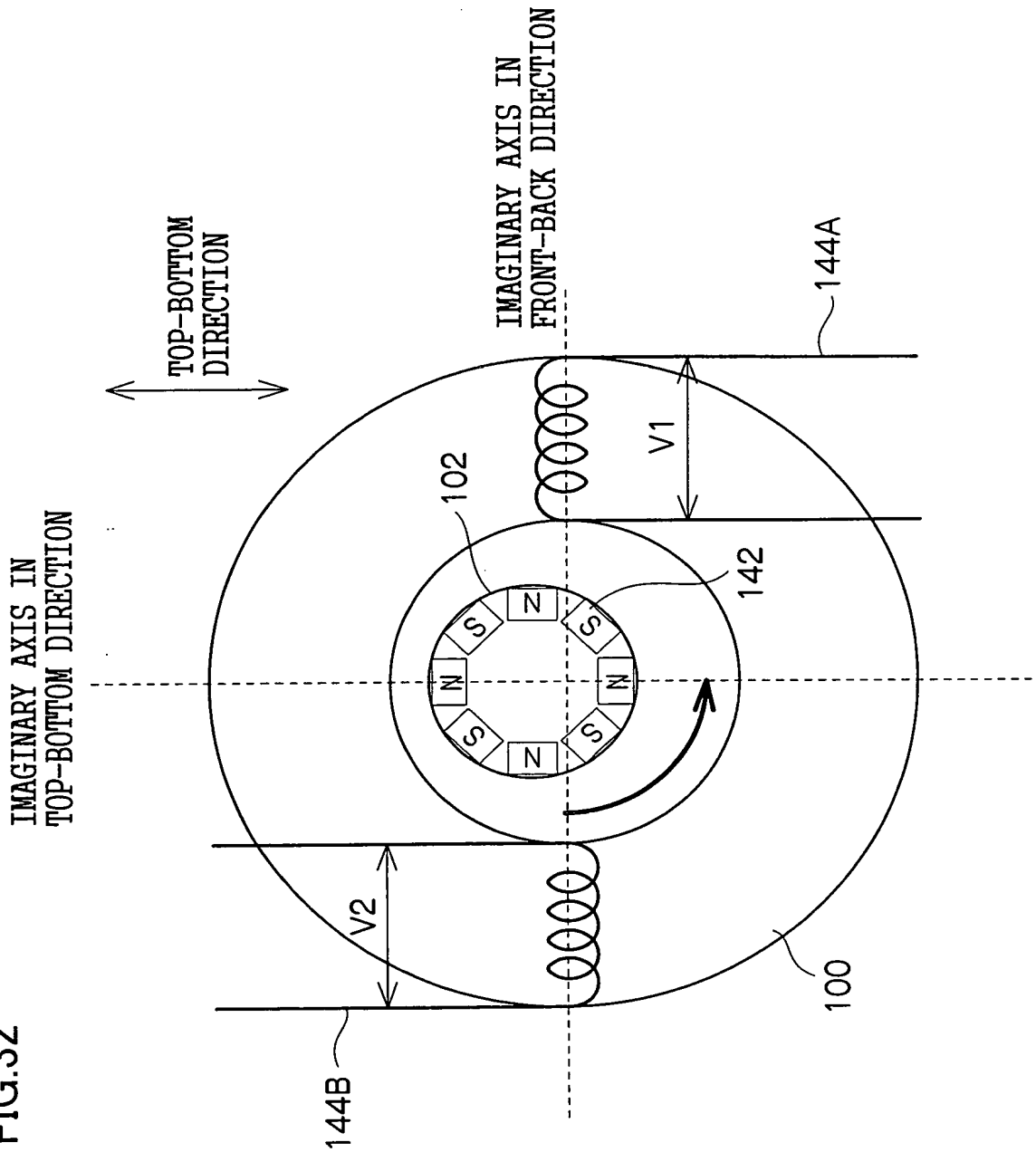

IMAGINARY AXIS IN
TOP-BOTTOM DIRECTION
TOP-BOTTOM
DIRECTION
IMAGINARY AXIS IN
FRONT-BACK DIRECTION
144A
V1
102
142
N
S
V2
144B
100

FIG.33

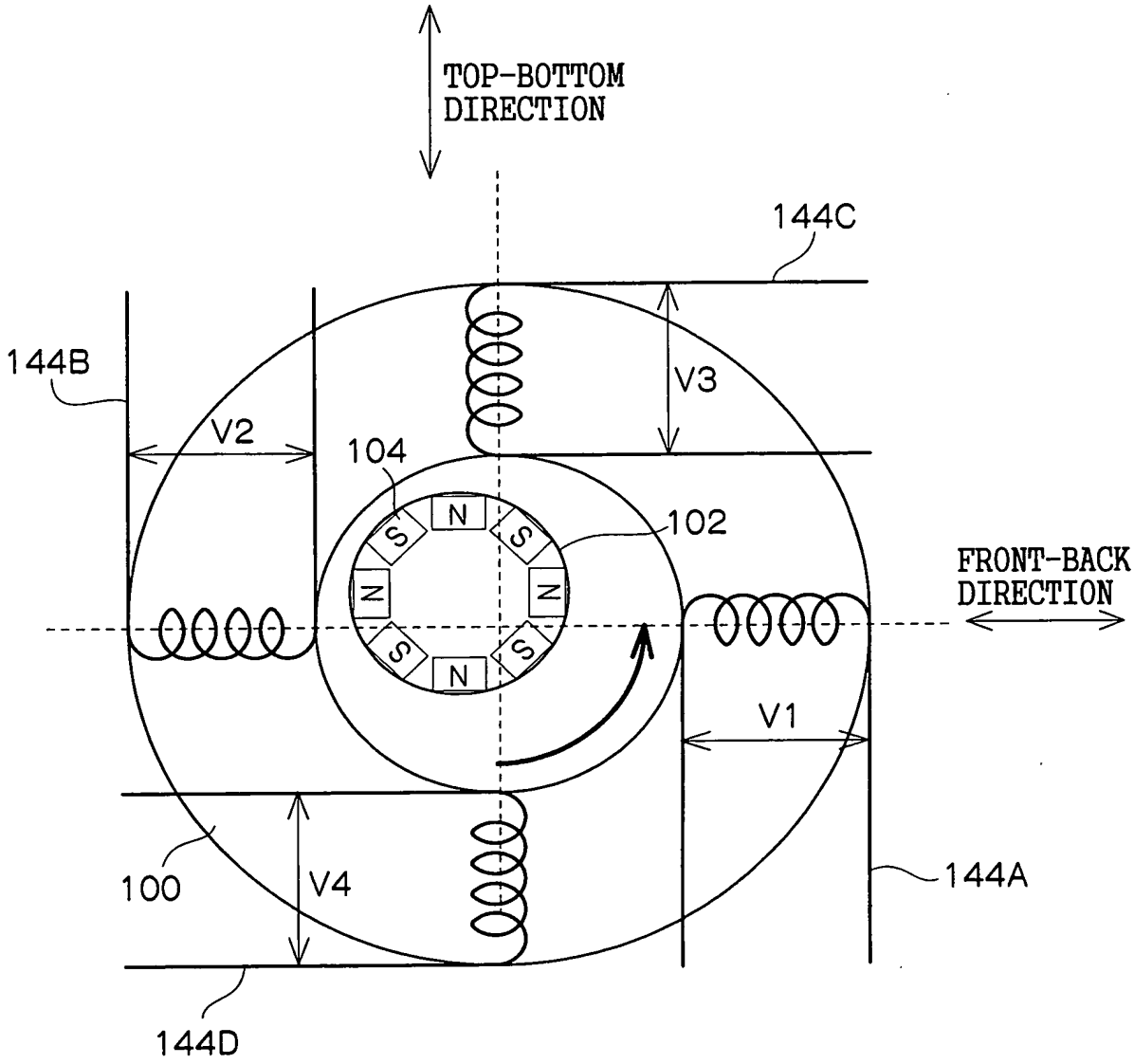
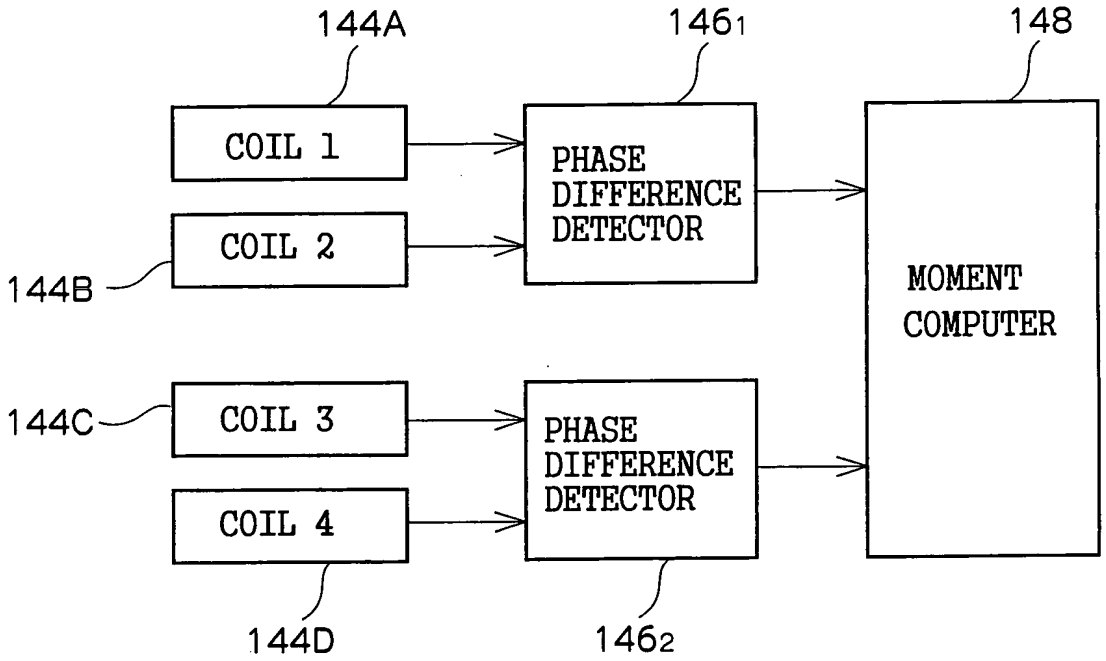

TOP-BOTTOM
DIRECTION
144C
144B
V3
V2
104
102
N
S
FRONT-BACK
DIRECTION
V1
100
V4
144A
144D

FIG.34


144A
1461
148
COIL 1
COIL 2
144B
PHASE DIFFERENCE DETECTOR
MOMENT COMPUTER
144C
COIL 3
COIL 4
PHASE DIFFERENCE DETECTOR
144D
1462